

*Measuring Congestion and Emissions: A Network Model for Mexico City*

by

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S.B., Civil Engineering  
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Submitted to the Department of Civil and Environmental Engineering  
in Partial Fulfillment of the Requirements for the Degree of

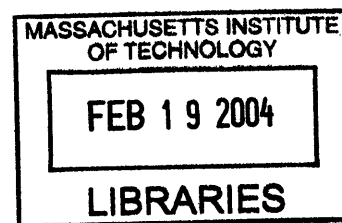
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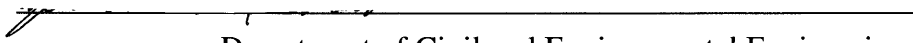
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**BARKER**



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By Yasuaki Daniel Amano

Submitted to the Department of Civil and Environmental Engineering  
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Master of Science in Transportation

## Abstract

Congestion is a major problem for the major cities of today. It reduces mobility, slows economic growth, and is a major cause of emissions. Vehicles traveling at slow speeds emit significantly more pollutants than vehicles traveling at free flow speeds. It is therefore important to determine the extent of congestion in a city, and its impact on the environment.

This thesis focuses on congestion in the Mexico City Metropolitan Area. Mexico City is one of the largest cities in the world, and faces severe levels of congestion and emissions. Although much of the transportation trips are made by high capacity modes such as buses and colectivo minibuses, a growing population and increasing automobile ownership rate will further exacerbate the city's mobility and environment.

In order to measure the level of congestion in Mexico City, a network model was built. Combining data from a 1994 origin destination survey and the 2000 census with a digitized roadway network, we were able to determine the state of vehicle speeds on roadways throughout the city. This speed distribution was then used in the MOBILE6 model to estimate the total emissions from road based transportation sources.

The network model was also used to study the extent of congestion and emissions for various future infrastructure projects. An analysis was done for a year 2025 growth scenario, where Mexico City continues to grow in population and size. The impact of two infrastructure improvements on congestion was also studied.

The results of the model show that while it is a useful tool for studying congestion on a citywide scale, the effects of local infrastructure changes cannot be accurately modeled. Further work on improving the model may yield improved results on a greater level of detail.

Thesis Advisor: Joseph M. Sussman

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# Table of Contents-

Abstract .....	3
Acknowledgements.....	5
List of Figures .....	8
List of Tables .....	9
Chapter 1 - Introduction.....	10
1.1 Background on Transportation and Emissions .....	10
1.2 Background on Mexico City.....	11
1.2.1 History of Emissions in Mexico City.....	13
1.2.2 Background on Emissions.....	14
1.2.3 History of Transportation in Mexico City .....	17
1.3 Objective .....	20
Chapter 2- Impacts of congestion .....	22
2.1 What is congestion? .....	22
2.2 Why model congestion?.....	23
2.3 How can we model congestion? .....	25
Chapter 3- Methodology .....	27
3.1 Background.....	27
3.2 Chronology of Research .....	27
3.3 Roadway network description.....	29
3.4 Modeling Assumptions .....	34
3.5 Modeling process .....	35
Chapter 4- Results.....	37
4.1 Speed Distribution .....	38
4.2 Emissions estimates .....	39
4.3 Spatial representation.....	41
4.4 Infrastructure improvement analysis.....	43
4.4.1 <i>Segundo Piso</i> addition.....	43
4.4.2 Metro expansion.....	46
Chapter 5- Conclusions.....	49
5.1 Summary of results .....	49
5.2 Improvements to the network model .....	49
5.3 Limitations of the network model.....	51
5.4 Future work.....	52
References- .....	57

## **List of Figures**

Figure 1.1- DF and EM boundaries in the MCMA

Figure 1.2- Road and Rail Network in the Mexico City Metropolitan Area

Figure 1.3- Mexico City Metro System

Figure 1.4- Evolution of Mode Share in the Federal District, 1986-1998

Figure 2.1- Emissions vs. Vehicle Speed for HC

Figure 2.2- Emissions vs. Vehicle Speed for CO

Figure 2.3- Emissions vs. Vehicle Speed for NO<sub>x</sub>

Figure 3.1- Speed vs. Flow relationship

Figure 3.2- Vehicle Usage According to Hour of the Day

Figure 3.3- Vehicle Usage According to Day of the Week

Figure 3.4- Volume/Capacity Ratio vs. Vehicle Speed Plot for a Roadway with a Free-flow Speed of 50 kph

Figure 3.5- Structure of the network model

Figure 4.1- Transcad Roadway Network of the Mexico City Metropolitan Area

Figure 4.2- Number of Vehicles Traveling at 5 to 80 kph Each Hour, 1994 OD Data

Figure 4.3- 1994 and 2025 Speed Distribution

Figure 4.4- Vehicle speed vs. emissions for CO, 1994 data

Figure 4.5- Spatial Representation of Congestion for 1994 Data

Figure 4.6- Spatial Representation of Congestion for 2025 Data

Figure 4.7- Impact of Segundo Piso Addition on 2025 Vehicle Speed Distribution

Figure 4.8- Spatial Representation of 2025 Data with Segundo Piso Addition

Figure 4.9- Path for Line C Metro Expansion

Figure 5.1- Comparison between skeletal and full roadway networks



Figure 5.2- Bottleneck congestion scenario

### **List of Tables**

Table 1.1- Transport's Contribution to Total Emissions in the MCMA

Table 3.1- TransCAD Model Inputs and Outputs

Table 4.1- Emissions Data for 1994

Table 4.2- Emissions Data for 2025

Table 4.3- Emissions Data for 2025 With Segundo Piso

Table 4.4- V/C Ratios on Roadways Parallel to New Metro Line

## **Chapter 1 - Introduction**

### **1.1 Background on Transportation and Emissions**

Transportation is a critical component of our society. Without an efficient transportation system, people can spend a significant part of the day in a traffic jam, waiting for a subway, or traveling on a poorly planned bus route. Cities with efficient transportation systems can reach high standards of living, and are attractive to residents and businesses alike. Jobs become more accessible, deliveries can be made on time, and travel times decrease. However, a balance between the different modes of transportation is critical for the city to function with good mobility and a healthy environment.

All trips made within a city can be divided into two categories- private trips and public trips. Private trips are generally served by low occupancy vehicles, such as a private automobile. These low-capacity vehicles place a significant strain on the road infrastructure network. Rush hour traffic jams are typically the result of commuters traveling to or from work using private automobiles. However, private automobiles enable the owner to travel anywhere in the city at any time, giving him or her nearly complete freedom of mobility. The convenience of this freedom has made private trips attractive to anyone who can afford a car.

Public trips are taken on various forms of public transportation, such as buses, trains, or carpools. The riders share the service with others, and travel along a set route. Because many riders travel on one vehicle, it is a very efficient mode of transportation, and places far less strain on road infrastructure than private trips. Daily commuters traveling by train or bus to/from work in the city can significantly reduce congestion during rush hour. However, public trips give far less freedom of mobility. Trips must be taken along a subway line, or a bus route. Not all destinations may be easily accessible by public transportation, or may require a significant number of transfers. Public transportation users are often people who have a routine destination that is easy to reach such as a person traveling to work daily, or captive riders who cannot afford a car and

have no other choice. Cities with widespread public transportation coverage such as New York and Tokyo can handle a tremendous number of travelers each day while keeping congestion manageable.

There is an important balance between transportation, land use, and the environment. Sometimes referred to as the ‘Iron Triangle’, this balance consists of many complex relationships that have an impact on our daily lives. For example, a city with dense, centralized land use can be well-served by public transportation, resulting in high-occupancy trips and fewer emissions caused by vehicle engine combustion. On the other hand, a sprawling city promotes the use of private automobiles, putting stress on the road infrastructure and emitting harmful pollutants into the air. This thesis discusses transportation in Mexico City as an example of a once dense and centralized city that has become a sprawling metropolitan area plagued by congestion and harmful pollutants.

## 1.2 Background on Mexico City

Mexico City is the economic, political, and industrial center of the nation of Mexico. With a population of 18 million people, the Mexico City metropolitan area is one of the largest cities in the world. In addition to being the federal capital of Mexico, the city is divided into two parts- the central Federal District (DF) and the surrounding State of Mexico (EM). As a result, many of the city’s bureaucratic offices are divided into these two politically independent and sometimes, uncooperative municipalities.

The Federal District of Mexico City is composed of the old city center and the southern mountains. Up until a few decades ago, most of the city’s residents lived in this area. Composed of 16 zones called *delegaciones*, the Federal District contains the administrative offices and commercial headquarters for much of the city. The Federal District, with its high concentration of commercial activity, is one of the wealthiest areas of Mexico.

Surrounding much of the Federal District is the State of Mexico. The State of Mexico is rapidly growing in population as people seeking jobs flock to the city from the rest of the country. The State of Mexico is significantly poorer than the Federal District, with large areas of low-income housing and informal or illegal settlements. Figure 1.1 shows the entire Mexico City Metropolitan Area (MCMA).

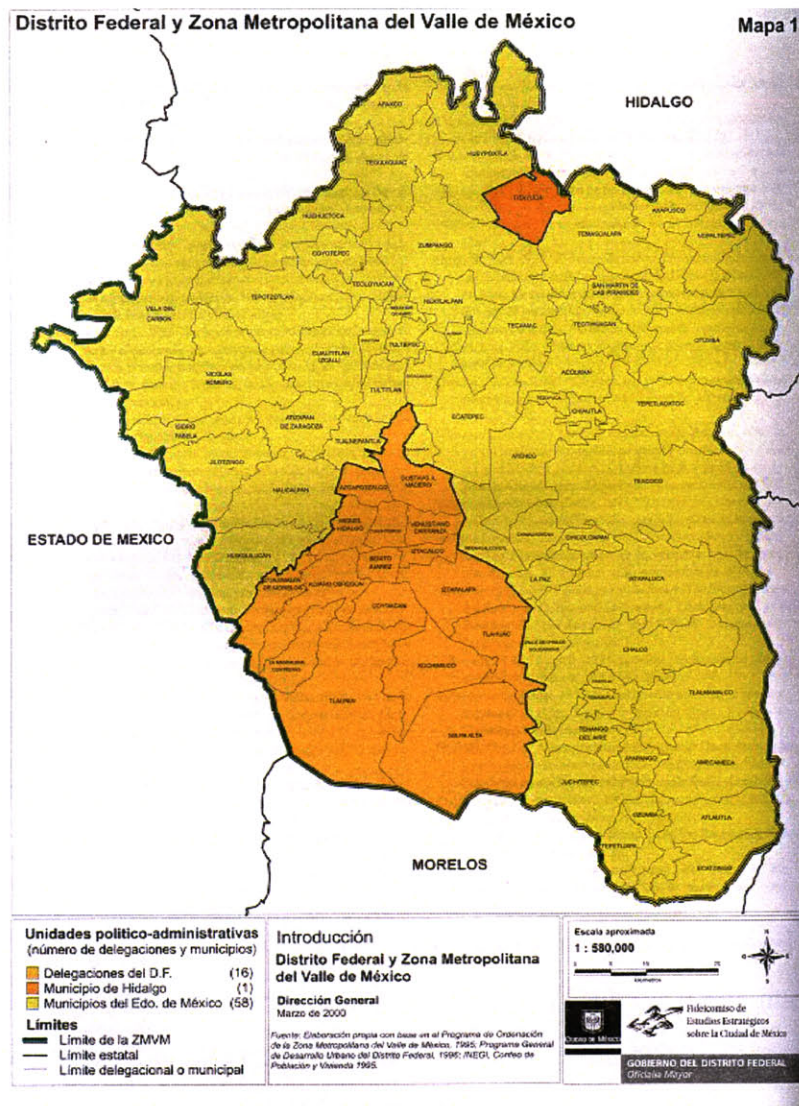


Figure 1.1- DF and EM boundaries in the MCMA  
Source: GDF (2000)

### 1.2.1 History of Emissions in Mexico City

Thirty years ago, Mexico City residents enjoyed clean, crisp air and beautiful views of the mountains and volcanoes surrounding the city. However, over the past few decades the city has become plagued with high concentrations of air pollutants. This can be traced to a variety of reasons.

#### Topography-

The geographic location and local topography of Mexico City is problematic from an emissions viewpoint. The city is located at an elevation of 2,200 meters, where the thin mountain air is low in oxygen. As a result, fuel combustion becomes less efficient and emissions from fuel burning sources are increased. Solar radiation is also increased, resulting in higher levels of ground level ozone, or 'smog.'

The city is also situated in a valley, surrounded on three sides by mountains and volcanoes, with elevations ranging up to 4,000 meters. These mountains serve as a barrier, trapping air inside the valley and preventing the circulation of pollutants out of the city. In addition, much of the city's high polluting industries are located on the open north side of the valley. With the wind blowing into the valley for much of the year, the emissions from these industrial sources also become trapped in the city.

#### City Development-

Over the past 30 years, Mexico City has developed from a small dense city situated mostly around the old center into a large, sprawling metropolis. The population in the denser Federal District has slowly decreased since 1975, while the State of Mexico has seen much of the city's population growth. Due to the decentralization of the city, trips have become longer, resulting in higher emissions from transportation sources. Industries have also moved into the city, attracted by a large labor force and a huge consumer market.

In the U.S., urban sprawl is caused by the population moving out of the city into the surrounding countryside, often called suburbanization. This is often due to people desiring a higher level of privacy and personal space, and these areas often have high property values. However, in Mexico City, sprawl is caused by the massive immigration of people seeking work. Because the city center is expensive, many people cannot afford to live in the Federal District, and settle in the surrounding State of Mexico. Many “illegal” or informal settlements have been developed around Mexico City, with little access to city services or formal public transportation. Only semi-formal public transportation sources such as colectivos, or minibuses reach these areas. Sprawl is a primary cause of congestion.

The increased levels of pollutants in Mexico City have had a serious negative social and economic impact. Pollutant-sensitive illnesses such as asthma and lung disease have become a serious problem in the city. The mountains surrounding the city are no longer visible except on the clearest of days. On days with particularly high levels of emissions, emergency procedures take effect which shut down businesses and factories until emissions levels are restored to an acceptable level. This results in serious economic losses.

Over the past few years, the emissions levels in the city have slowly decreased. With tougher emissions regulations, the number of emergency procedures has dropped from a peak of 80 days in 1995 to 5 days in 1999. However, the city will continue to grow to an expected population of 25 million people by 2025, so further steps must be taken to continue to reduce emissions.

### 1.2.2 Background on Emissions

There are a number of pollutants that directly come from the emissions produced through vehicular exhaust, as well as those that form in the atmosphere through secondary chemical reactions. Major pollutants from transportation sources include

particulate matter (PM10), sulfur oxides (SO<sub>x</sub>), nitrous oxides (NO<sub>x</sub>), hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO<sub>2</sub>).

Particulate matter consists of tiny particles of solid or semi-solid material found in the atmosphere. These particles can be composed of both organic and inorganic material, such as dust, pollen, or soot. Particulate matter that is small enough to breathe in is known as PM10, or particles with a diameter smaller than 10 microns. These particles are small enough to enter the respiratory system and lungs, increasing the likelihood of sickness such as bronchitis and causing permanent damage if a person is exposed over a long period of time. Areas with high amounts of PM10 often see an increase in the number of asthma cases and other respiratory diseases. PM10 can also cause buildings, as well as plant life, to deteriorate and reduces visibility levels.

Most sulfur oxides are found in the form of sulfur dioxide (SO<sub>2</sub>), a colorless gas that is often associated with the smell of a struck match. This gas can combine with water vapor to form H<sub>2</sub>SO<sub>3</sub>, a mildly corrosive liquid. Further interaction with atmospheric oxygen produces H<sub>2</sub>SO<sub>4</sub>, or sulfuric acid, which is highly toxic and corrosive. Acid rain is a product of sulfuric acid mixing with water vapor. Sulfur oxides are often generated from the combustion of sulfur-laden gasoline or coal. Sulfur is commonly found in varying concentrations in fossil fuels. The petroleum produced and used in Mexico contains very high amounts of sulfur. Health effects of sulfur oxides and its byproducts include respiratory irritations, eye irritation, and breathing difficulty. Sulfur oxides are also harmful to plants that are sensitive to the acidity of the soil. Due to the corrosive nature of sulfur oxides, it can cause damage to buildings, paint, and electrical components. The Mexican state owned petroleum company, PEMEX, is currently upgrading its facilities to reduce the levels of sulfur in gasoline from 300 to 30 parts per million.

Nitrous oxides are composed of NO and NO<sub>2</sub>, toxic gases that are also precursors to acid rain. Nitrous oxides are created through the high temperature combustion of

gasoline. Health effects include respiratory irritations and breathing difficulty. Nitrous oxides also react with hydrocarbon compounds and sunlight to form ground level ozone.

Hydrocarbons are chains of carbon and hydrogen produced through incomplete combustion of gasoline or the evaporation of gasoline. A precursor of ground level ozone, hydrocarbons are also carcinogenic and cause respiratory irritations.

Ozone (O<sub>3</sub>) is the product of the chemical reaction of nitrous oxides, hydrocarbon compounds, and sunlight. At high altitudes in the atmosphere, ozone is useful for blocking harmful ultraviolet rays from the sun. However, at ground levels it is highly corrosive and unstable, reacting with organic and inorganic material. Health effects include eye and respiratory irritations. Ozone is also very harmful to plant life, slowing their growth rate. Ozone reduces ground level visibility, and is often associated with smog.

Carbon monoxide (CO) is the product of incomplete combustion of gasoline, and is often found in areas with low levels of oxygen, such as high altitude areas. Carbon monoxide is a gas that can block the transfer of oxygen into the bloodstream, causing death at high concentrations. It can also cause serious damage to the nervous system, headaches, and nausea. Carbon dioxide (CO<sub>2</sub>) is generated through the complete combustion of gasoline. It has no serious health impacts, but is a greenhouse gas that traps heat in the atmosphere, causing ecological changes and damage.

Table 1.1 shows the contribution of emissions from transportation sources in Mexico City. Much of the SO<sub>x</sub> and PM contributions are from diesel engines on trucks and buses, while private autos are responsible for most of the HC emissions. Because transportation sources are responsible for a large portion of emissions, it is important to clearly understand the status of traffic in Mexico City.



	1994	1996a	1996b	1998
<b>PM<sub>10</sub></b>	4%*	25%	26%	51%
<b>SO<sub>x</sub></b>	27%	21%	21%	28%
<b>CO</b>	100%	100%	99%	98%
<b>NO<sub>x</sub></b>	71%	70%	77%	80%
<b>HC</b>	52%	33%	33%	36%

Table 1.1: Transport's Contribution to Total Emissions in the MCMA

\*N.B: in 1994, the contribution is of total suspended solids rather than just PM<sub>10</sub>

Sources: 1994 from Proaire, 1996a from the Proaire 2<sup>nd</sup> Report, and 1996b and 1998 from CAM (2000).

### 1.2.3 History of Transportation in Mexico City

Mexico City has a complex system of road and rail-based transportation infrastructure. With the city increasing in population and size, new infrastructure projects are being built to maintain a high level of mobility.



Figure 1.2- Road and Rail Network in the Mexico City Metropolitan Area

Source: <http://www.magellan.com>

The roadway network in the DF portion of the city consists of major arterial roadways traveling in each cardinal direction. These *ejes viales* or “road axes” form a grid pattern traveling away from the old city center. Throughout this grid system, there are also many diagonal roadways such as the broad *Paseo de la Reforma*. There are very few highways near the city center. However, by using one-way streets and signal synchronization, some arterial roadways can reach relatively high free flow speeds. Many of these arterial roadways have an “exclusive” bus rapid transit lane, but due to poor enforcement, they are often used by private vehicles or colectivos for travel or parking.

One limited access highway called the *Circuito Interior* or “Inner Loop” forms a ring around the city center. An outer loop highway called the *Periferico* forms a circumference around the city. These highways often run parallel with adjacent service roads, with frequent on and off ramps. As a result, friction between these two roadways reduces vehicle free flow speeds. These highways have quickly outgrown their capacity, and there is currently a discussion to build a *Segundo Piso*, or a second story viaduct above the *Periferico*.

Because Mexico City is located in the center of the country, it serves as a hub for many of the national highways. Due to the surrounding mountainous terrain, there are very few roadways traveling in and out of the city. The primary method for traveling into and out of the city is on these highways, snaking through the mountain passes. These highways terminate at the city periphery, often merging with the *Periferico*. In order to travel through the city, one must use the circumferential highway, or travel on the arterial roadways through the city center.

Mexico City also has a complex public transportation system. A rail-based Metro system provides service to a large portion of the DF and one corridor in the EM. Consisting of 11 lines and 175 stations, the Metro is one of the largest systems in the world, carrying 5 million passengers daily. The current fare for one trip on the metro is 2

Mexican Pesos, or about 20 cents. Terminal stations along the city edge are often major intermodal hubs, with transfers from the city bus and colectivo to the metro.



Figure 1.3- Mexico City Metro System  
Source: [www.metropla.net](http://www.metropla.net)

For political reasons, most of the metro lines are located within the Federal District. As a result, buses and colectivos operate out of the terminal stations to serve the surrounding State of Mexico. The stations at Pantitlan and Indios Verdes are major transfer points, serving 500,000 passengers per day. However, many colectivo routes run parallel with metro lines, creating competition between the two modes.



Following the collapse of the city bus system in the 1980's, colectivos have recently become the dominant form of public transportation in Mexico City. Colectivos can range from the size of a minivan to a small bus. These privately owned vehicles make stops along a specified route, and provide frequent service. One of the few transportation options for residents in informal settlements or outlying areas, colectivos are mostly used by lower income workers.

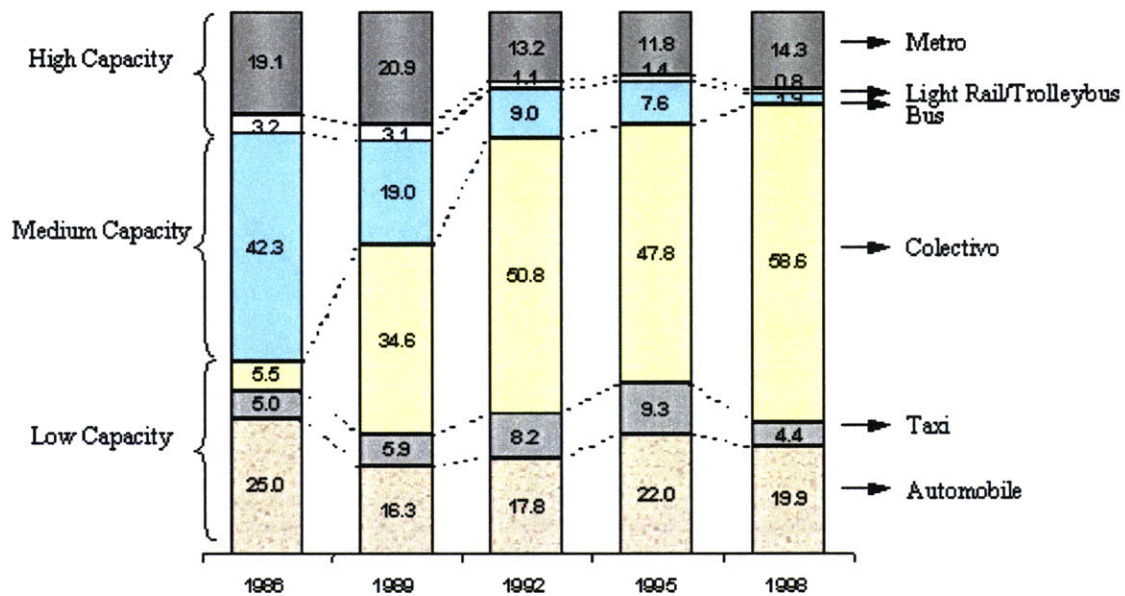


Figure 1.4- Evolution of Mode Share in the Federal District, 1986-1998

Source: SETRAVI (1999), quoting: 1986, CGT y COVITUR, DDF; 1989 - 1998 Poder Ejecutivo Federal, 3er Informe de Gobierno.

### 1.3 Objective

The objective of this thesis is to determine the level of congestion in Mexico City, understand its impacts on mobility and the environment, and model the effects of various scenarios, including projected population growth and infrastructure improvements.

The organization for topics and questions answered in this thesis are as follows:

## Chapter 2

- What is congestion, and why is it important to model it?
- How does congestion impact emissions?
- How can we model congestion for Mexico City?

### Chapter 3

- Description of the methodology for modeling congestion
- Modeling assumptions

### Chapter 4

- Description of results from the congestion modeling
- Description of trends in increased congestion and emissions for the future
- Spatial representation of congestion in Mexico City

### Chapter 5

- Discussion of results
- Possible model improvements
- Model caveats
- Possible future work

## **Chapter 2- Impacts of congestion**

### **2.1 What is congestion?**

Congestion is a general term to describe what occurs when the demand for a transportation system exceeds the supply. For roadways, this occurs when traffic along a route exceeds the routes capacity. Congestion can range from light levels where vehicles are still flowing but at a slower pace, to severe levels where vehicles are at a standstill. It can be localized on one roadway segment, or it can spread to connecting roadways as people try to find a faster path. It can occur on a daily basis along a heavily traveled corridor, or it can occur randomly at any time, caused by a roadblock or accident.

Congestion is a broad term used to describe travel delay, and it can be measured in a variety of ways. It can be measured as increased travel time caused by slower vehicle speeds. It can be measured by the volume to capacity ratio on a roadway, with volume exceeding a roadways optimal capacity to be considered “congested.”

There are many factors that can affect congestion. On the demand side, population growth and smaller households tend to increase the number of trips taken, resulting in increased congestion. Higher GDP per capita or income rates may indicate that a household is more likely to own and use a car. Longer trips caused by urban sprawl also increase congestion. On the supply side, congestion can be reduced by having an efficient public transportation system to shift people away from cars to metro or bus. Congestion can be reduced by a toll, giving drivers an incentive to choose another mode or another time of day to travel. Congestion can also be reduced through careful land use and zoning, and controlling land development.

## 2.2 Why model congestion?

Congestion is a concern that affects many aspects of life. Delays caused by congestion can cause significant financial loss. Daily commute time increases due to congestion, reducing worker productivity and accessibility to jobs. Congestion causes delays in freight delivery, resulting in longer vehicle cycles and the need for more trucks to maintain an acceptable level of service, which in turn causes more congestion. The stop-and-go nature of congestion also results in increased fuel consumption and wears down vehicles at a faster rate.

Congestion also has many social ramifications. Longer travel times are an inconvenience for everyone, from children traveling to school to people traveling to work or shop. Congestion causes roadways to become more prone to accidents, with reduced following distances and increased stress.

Finally, congestion is a major environmental concern. As vehicles travel at slower speeds or in stop-and-go traffic, they produce greater emissions per vehicle-kilometer traveled. Vehicles are in use for a longer time, and the stop-and-go driving cycle results in increased fuel consumption. According to a World Bank study, hydrocarbon and carbon monoxide emissions and nitric oxide emissions in diesel vehicles significantly increase at very low and very high vehicle speeds, while gasoline vehicles emit more pollutants at very low vehicle speeds.

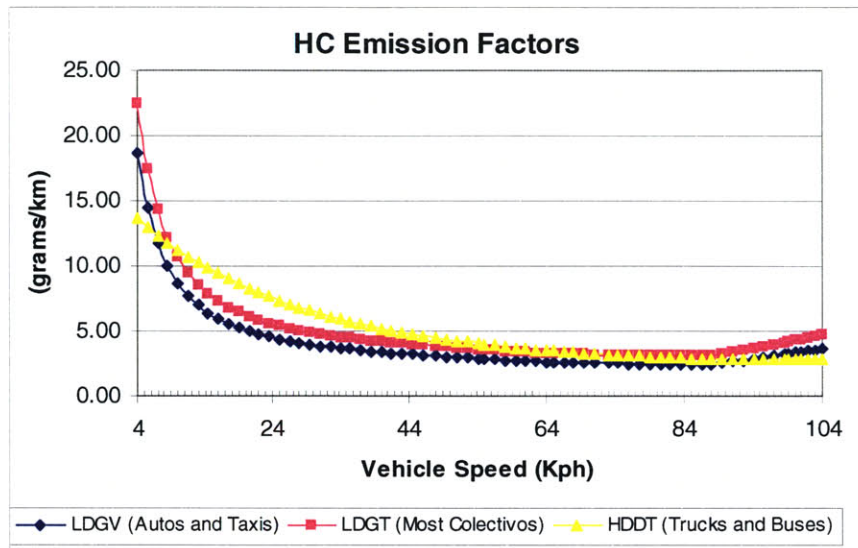


Figure 2.1- Emissions vs. Vehicle Speed for HC

Source: World Bank Report, Air pollution from motor vehicles: standards and technologies for controlling emissions, 1996

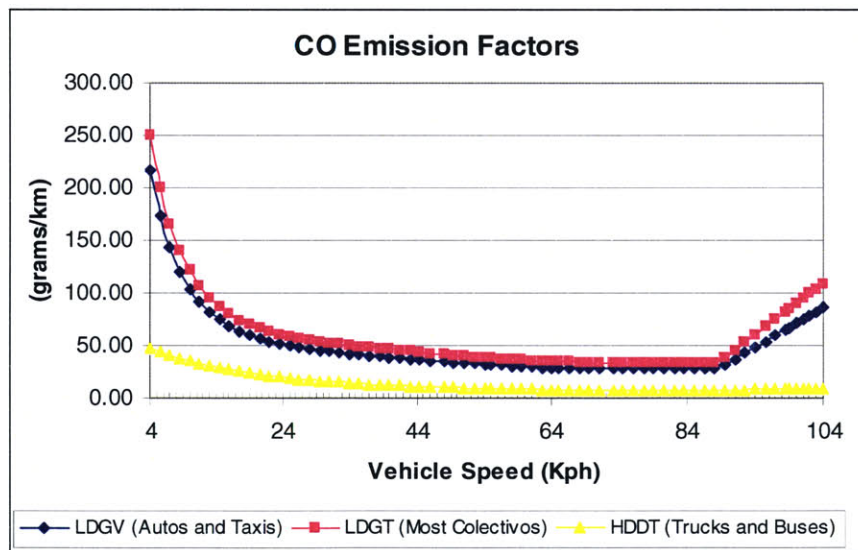


Figure 2.2- Emissions vs. Vehicle Speed for CO

Source: World Bank Report, Air pollution from motor vehicles: standards and technologies for controlling emissions, 1996



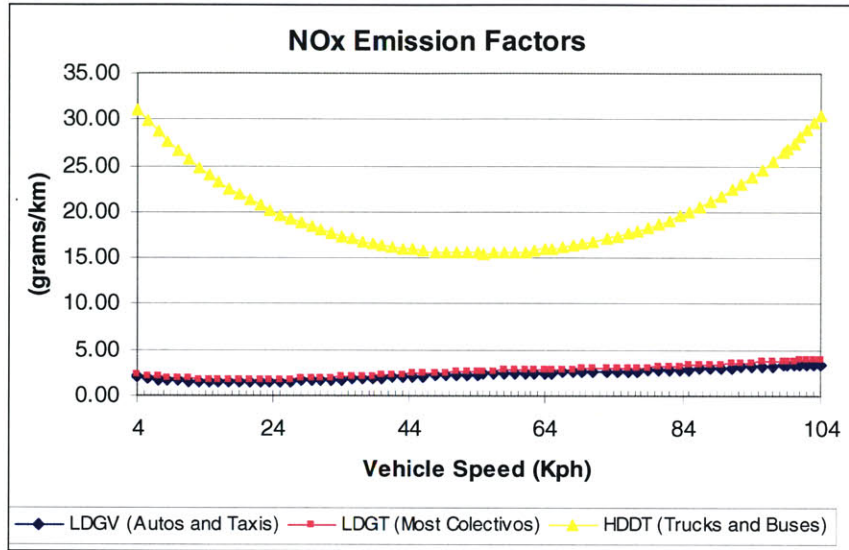


Figure 2.3- Emissions vs. Vehicle Speed for NOx

Source: World Bank Report, *Air pollution from motor vehicles: standards and technologies for controlling emissions, 1996*

In previous emissions inventories, the estimated emissions of vehicles in Mexico City did not take congestion or vehicle speed into consideration. The emissions factor for each vehicle type was based on the assumption that all vehicles are traveling at 32 kilometers per hour. Because there was no network model to estimate vehicle speeds and driving cycles, the Metropolitan Environmental Commission (CAM) had to assume a vehicle speed in order to obtain the emissions inventories. Based on the emissions graphs for NOx, CO, and HC, this speed is at a relatively low emissions point. However, in reality, vehicles in Mexico City are traveling over a wide distribution of speeds, ranging from stop-and-go congested roadways to fast moving highways. As a result, the current estimate for vehicle emissions in Mexico City likely underestimates the true emissions caused by vehicles. To remedy this, it is necessary to determine the distribution of speeds for all vehicles.

### 2.3 How can we model congestion?

Congestion can be determined by a variety of methods. One method involves measuring vehicle speed patterns throughout the city. Sensors are placed on a number of vehicles, and the vehicles movement and speed are recorded. This data can then be

aggregated to obtain a distribution of speeds for all vehicles. However, this technique is not very adaptable, and cannot be used to estimate congestion for future growth or infrastructure improvements.

Another method uses the supply-demand relationship to model congestion. Using census data and surveys, it is possible to approximate the origin and destination for all trips. This OD table quantifies the demand for all personal transport between all zones in the city. This data is then assigned to the roadway network, representing the supply side of the relationship. This model is very flexible, because increased trip demand or supply side infrastructure improvements can be modeled in this method. This approach provides the basis for the research outlined in this thesis. Chapter 3 goes on to describe this approach in detail.

## Chapter 3- Methodology

### 3.1 Background

Urban transportation authorities often use network modeling in order to determine the performance of the regional roadway network. Incorporating the entire road network into the model, authorities can model the effects of road closures, roadway and public transit infrastructure improvements, and urban growth and sprawl. These models grow in complexity as the city size increases, and require a significant amount of data, such as a citywide origin-destination matrix and roadway characteristics, such as roadway type, number of lanes, and free-flow travel speed. Two of the most widely used roadway network modeling programs are EMME/2, designed by a group of professors at the University of Montreal, and Transcad, designed by Caliper Corporation. For the purposes of this thesis, Transcad is used.

### 3.2 Chronology of Research

Before taking the network modeling approach, a simpler method was attempted to measure the vehicle speeds and level of congestion in Mexico City. The Texas Transportation Institute had recently completed a mobility survey for 68 cities in the United States. The data gathered from this survey included a roadway congestion index, the number of lane-miles of roadway, and the city population. This Roadway Congestion Index, or RCI, was a way to classify a level of congestion, taking into consideration the different roadway types and network layout of each US city. Using this data, regressions were performed in an attempt to calculate the congestion index using city specific data. The following equation gives the general format of these regressions.

$$\text{Congestion index(city)} = \text{Beta1} + \text{Beta2} * \text{Lane-miles of roadway(city)} + \text{Beta3} * \text{Population(city)}$$

Benefits of this model were its simplicity and macroscopic scope. Unfortunately, there was not enough data to give an accurate estimation of the congestion levels, and it was likely that other variables that were not included in the survey had a large impact on congestion, such as city density and automobile ownership rates.

One other approach taken to measure congestion levels in Mexico City involved vehicle flow data taken at various points on the roadway network. The Ministry of Transportation, or SETRAVI, used sensors to count the number of vehicles traveling each day at 41 points of the primary roadway network. This data was taken at 15 minute intervals, but did not distinguish between different types of vehicles, such as automobiles and buses. Using vehicle flow and speed relationships, an attempt at estimating the average vehicle speed was made. Unfortunately, due to the nature of this relationship seen in Figure 3.1, it was impossible to determine whether the vehicles were flowing in the uncongested or congested regime. It is possible that at one flow value, 2 vehicle speeds can be obtained- the vehicles may be sparse but moving quickly, or the vehicles may be bumper to bumper but moving slowly.

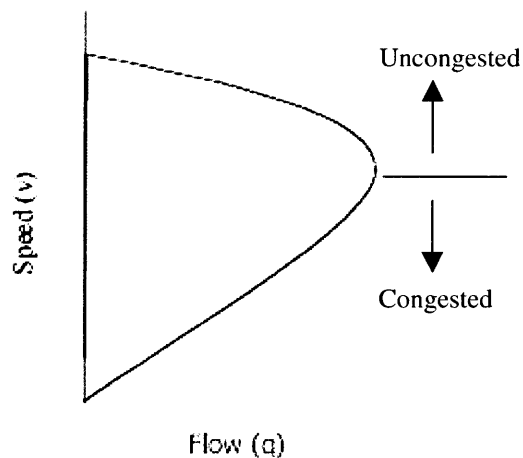


Figure 3.1- Speed vs. Flow relationship

As a result, additional data apart from only vehicle flow was required in order to measure the vehicle speed and congestion levels.

### 3.3 Roadway network description

Therefore, given the data and resources that were available at the time, we decided to develop a roadway network model of Mexico City. A roadway network model gives us many advantages over a simple regression or flow/speed model.

- A network model can be built in stages, starting with a skeletal network of primary roadways. If a greater level of detail is required, the model can be modified.
- A network model gives a spatial representation of the city. Congestion areas can be pinpointed, and a greater level of detail can be obtained over a general, macroscopic model. The network model can also be used in tandem with the atmospheric emissions model, which can show the effects of congestion on emissions.
- A network model can incorporate the effects and interactions between different modes of travel. For example, if a new metro line was constructed along a major roadway, the reduction of road based traffic along that segment can be modeled by changing the mode split for all trips along that corridor.
- A network model is based on measured data, and can be adapted to changing conditions in the city. The close ties between vehicle speed and vehicle trips/roadway capacity make this model more credible than a simple regression.

Transcad was chosen as the software to create the model due to its availability and compatibility with the GIS resources obtained from colleagues in Mexico City. Current atmospheric chemistry models and land use data are already in a GIS format, so results from both models can be compared in a similar format.

#### Model inputs-

Certain data is required before building the Transcad network model.

- An origin-destination (OD) matrix is necessary to determine the number of trips between the various areas in the city. These include work, school, shopping, and recreational trips taken throughout the day, as well as freight trips from within and outside the city. This data was gathered by Julia Gamas Buentello from a 1994 OD survey as well as census data from the National Institute of Statistics Geography and Information (INEGI). A 2025 OD matrix was created from projections of population and economic growth based on a future scenario by Rebecca Dodder. This scenario called for a widening of the wealthy/poor income gap, continued sprawl into the State of Mexico, and moderate economic growth.
- A mode split matrix is needed to determine the breakdown of trips into various modes of transportation, such as private auto, bus, metro, and colectivo. The mode split is determined by several factors- private auto trips are dependent on income level, or people who can afford cars, while colectivo and metro usage is dependent on the proximity of stops and routes. Combining the origin-destination matrix with the mode split matrix gives the total number of vehicle trips traveled between the various distritos.
- Roadway characteristic data is required for the model to distribute the trips throughout the network. This model uses a user equilibrium approach, where drivers use travel time to determine their trip route. As a result, the free-flow speed and roadway capacity are needed.
- Vehicle usage partitioned into time of day and day of the week is necessary in order to model the effects of work peak hours and weekend travel. Figures 3.2 and 3.3 show the trend of travel according to time.

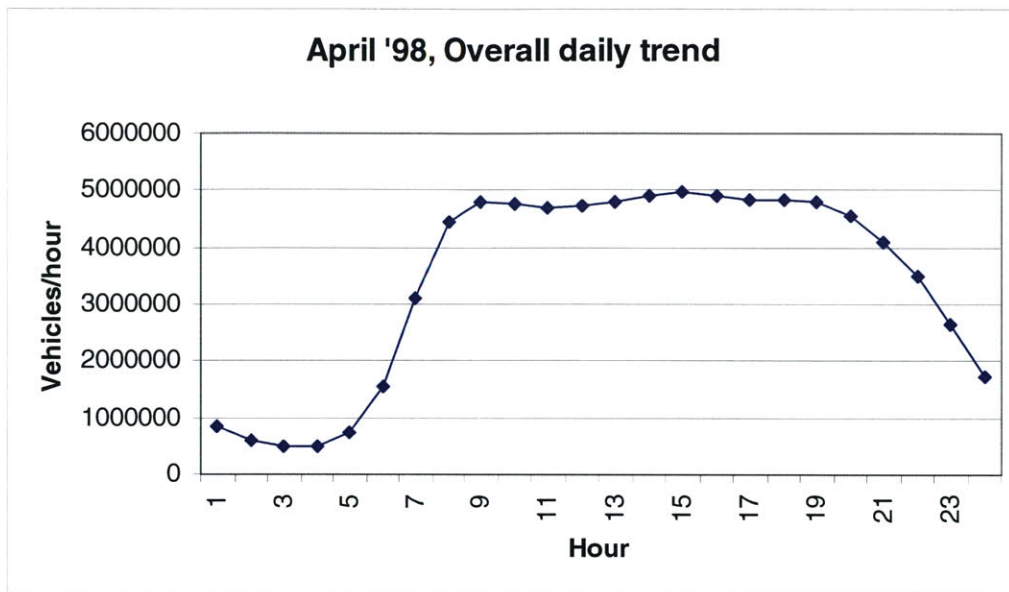


Figure 3.2- Number of vehicles passing 30 sensor locations in the MCMA according to the hour of the day

*Source: SETRAVI vehicle count data*

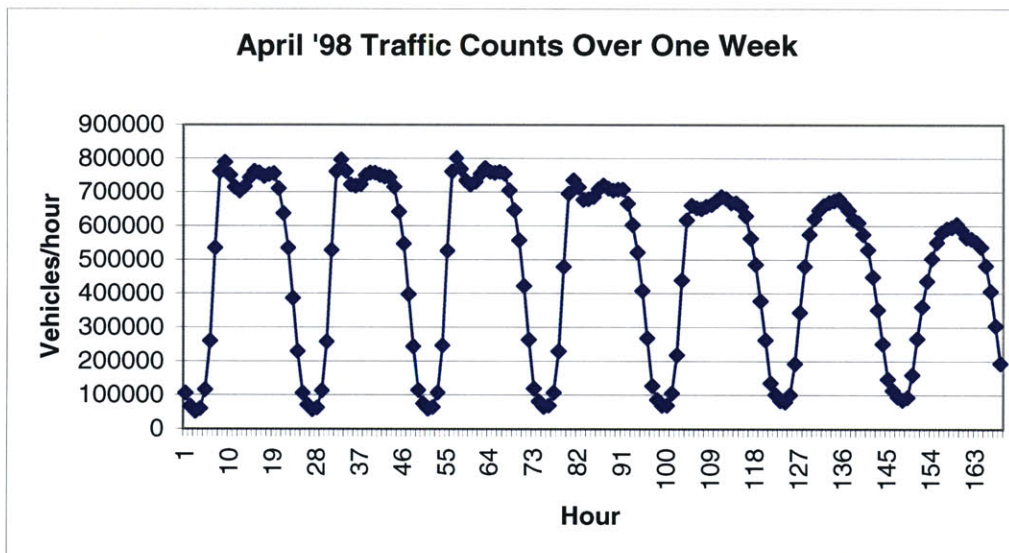


Figure 3.3- Number of vehicles passing 30 sensor locations in the MCMA according to day of the week, beginning with Monday

*Source: SETRAVI vehicle count data*

This data was taken from line counts along 30 major corridors in the city. Line counts are measured from sensors along the side of the road, which detect whenever any vehicle passes by. However, these sensors cannot differentiate between autos, buses, and trucks.

## Model Outputs-

The primary output of the Transcad model is the vehicle flows on each roadway segment. Using this data, it is possible to determine the Volume to Capacity (V/C) ratio and vehicle speed on each roadway segment. The determination of the model results can be characterized in the following way:

Model Inputs	Model Output	Derived Outputs
Roadway capacity (veh/hr)	Vehicle flow (veh/hr)	Volume/Capacity ratio
Free-flow speed (km/hr)		Congested vehicle speed (km/hr)
Number of trips between each distrito (veh/hr)		Vehicle travel time (hr)

Table 3.1- Transcad Model Inputs and Outputs

The volume/capacity ratio is the calculated vehicle flow divided by the roadway capacity. A roadway with a volume/capacity ratio less than or equal to one is considered uncongested. Once the volume/capacity ratio exceeds one, the roadway becomes noticeably more congested, lowering the vehicle speed at a drastic rate, as illustrated in Figure 3.4. When the roadway is holding 3 times the design optimal capacity, the vehicle speed approaches a crawl level.



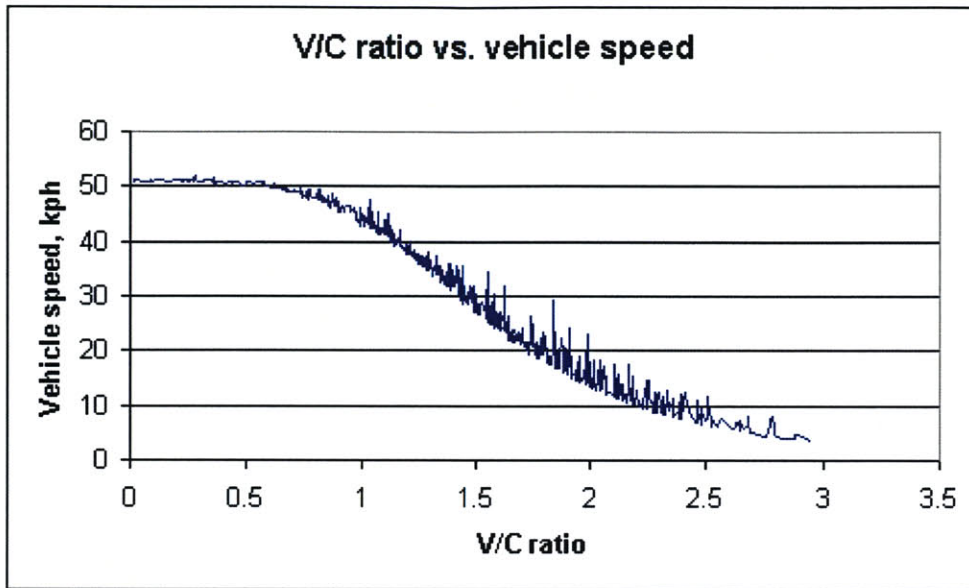


Figure 3.4- Volume/Capacity Ratio vs. Vehicle Speed Plot for a Roadway with a Free-flow Speed of 50 kph

The congested travel time is calculated using the following formula from the Bureau of Public Roads:

$$\text{Congested Travel time} = \text{Free-flow travel time} * (1 + a * (v/c)^b)$$

Where:

$v$  = roadway volume (veh/hr)

$c$  = roadway capacity (veh/hr)

$a$  and  $b$  are calibration parameters

The formula, known as 'BPR curves', begins with the free-flow travel time, and uses a multiplier based on the volume/capacity ratio to estimate the effects of congestion. Because this multiplier is exponential, congested roadways can quickly result in much longer modeled travel times.

Once the model has finished running, the flow and vehicle speed on each roadway link can be obtained. This data is aggregated to determine a citywide vehicle travel speed distribution. This speed distribution allows us to estimate emissions more accurately. The following figure summarizes the entire modeling process:

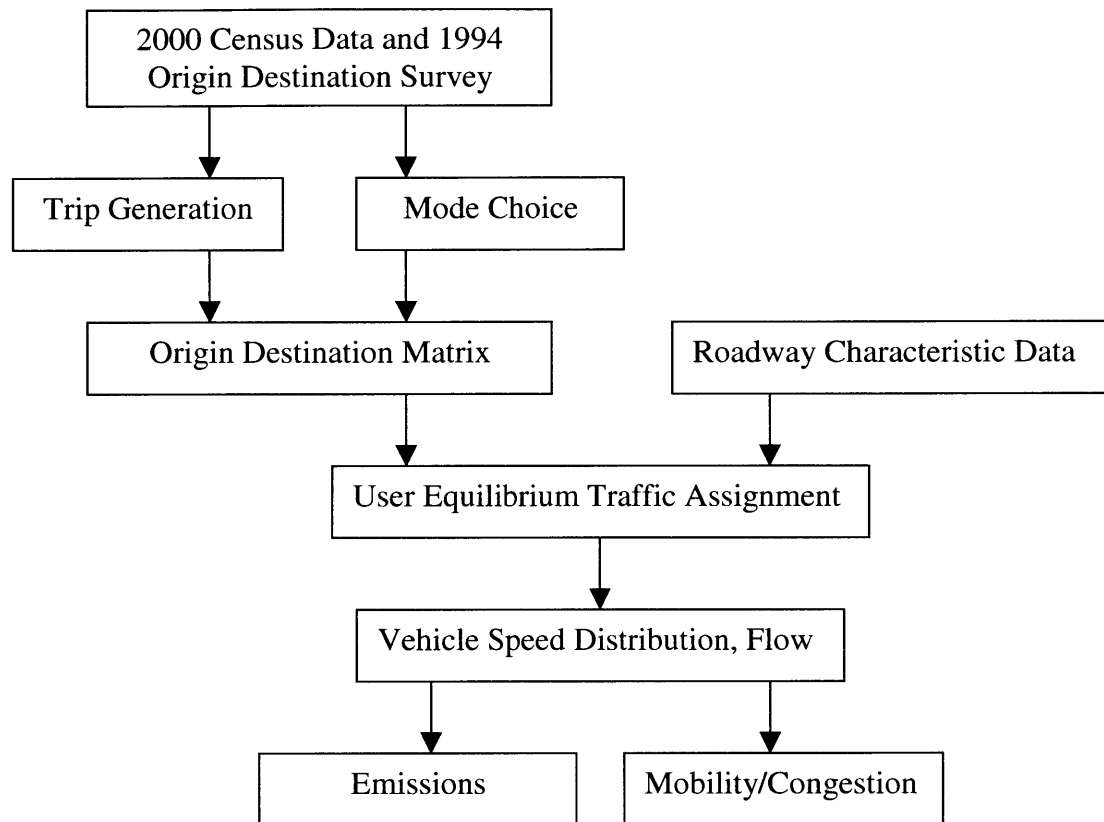


Figure 3.5- Structure of the network model

### 3.4 Modeling Assumptions

Several assumptions are required in order to make the network model more manageable.

- Because a skeletal roadway network is used, vehicle travel on secondary roadways is not modeled. It is assumed that a large percentage of vehicle trips is made on the primary roadways incorporated in the network.
- Freight assumptions regarding truck movement within the city and freight coming from outside the MCMA into the city are simplified. Freight is assumed to compose 10% of all vehicle flow in the city.
- Trucks, buses, colectivos, and automobiles each have a different impact on traffic flow. Larger vehicles such as trucks and buses tend to make vehicles travel at a slower speed for safety reasons, and colectivos make frequent stops, backing up

traffic behind it. Trucks and buses are assumed to equal 3 vehicles, while colectivos are assumed to equal 2 vehicles.

- Each road based transportation mode has an assigned occupancy rate. For simplicity, buses have 30 passenger occupancy, colectivos have 20 passenger occupancy, and taxis and private autos have an occupancy of 1 passenger.
- While one-way roads exist in Mexico City, this model is generated with all roads designated as two way. Refinements for one way roads are possible in the future.

### 3.5 Modeling process

The process for creating the network model involves the following steps:

- Obtain a roadway map of the MCMA, and transform it into a GIS-friendly format using ArcView. This map was made available by the National Institute of Statistics, Geography and Information, or INEGI.
- Partition the map into zones that will form the basis for the origin-destination matrix. “Distritos” were selected as a workable size zone for the purposes of this model. One distrito can be described as a neighborhood in a major city. The Mexico City Metropolitan Area is made up of 135 distritos.
- Digitize in the major roads passing through each distrito such that a basic roadway network is created. Each distrito should preferably have at least one north-south and one east-west roadway. This network is digitized in Transcad by tracing over the GIS map of the roadway network.
- For each roadway link in the network, specify the characteristics necessary for the model analysis. This includes, free-flow speed, number of lanes, and roadway capacity.
- Within each distrito, determine a ‘centroid’ that can be used as the point source/destination of all trips. Ideally, this point would be located at an intersection, allowing trips to disperse in all directions.

- Load the Origin-Destination vehicle trip matrix into the network, and allow Transcad to assign all road-based trips throughout the network until a user equilibrium is reached.
- Once the flows along each roadway reach equilibrium, use a volume/capacity ratio along with the free-flow speed to determine an average vehicle speed along each roadway. These 'BPR curves' are part of the Transcad software package.
- When these vehicle speeds are obtained, use an emissions factor model, such as MOBILE6, to determine an emissions 'multiplier'. This multiplier is used in conjunction with the emissions factor currently in use, and will give a more accurate estimate of emissions from vehicle sources.

Using the results of the model, it is possible to pinpoint congested corridors in the city and take steps to ease the congestion. Chapter 4 details the results obtained from the network model.

## Chapter 4- Results

The purpose of the Transcad model was to determine the level of congestion on Mexico City roadways, obtain a spatial representation of congestion, and model the effects of various infrastructure improvements and future growth scenarios. The entire Mexico City Metropolitan in the roadway network, is shown in Figure 4.1.

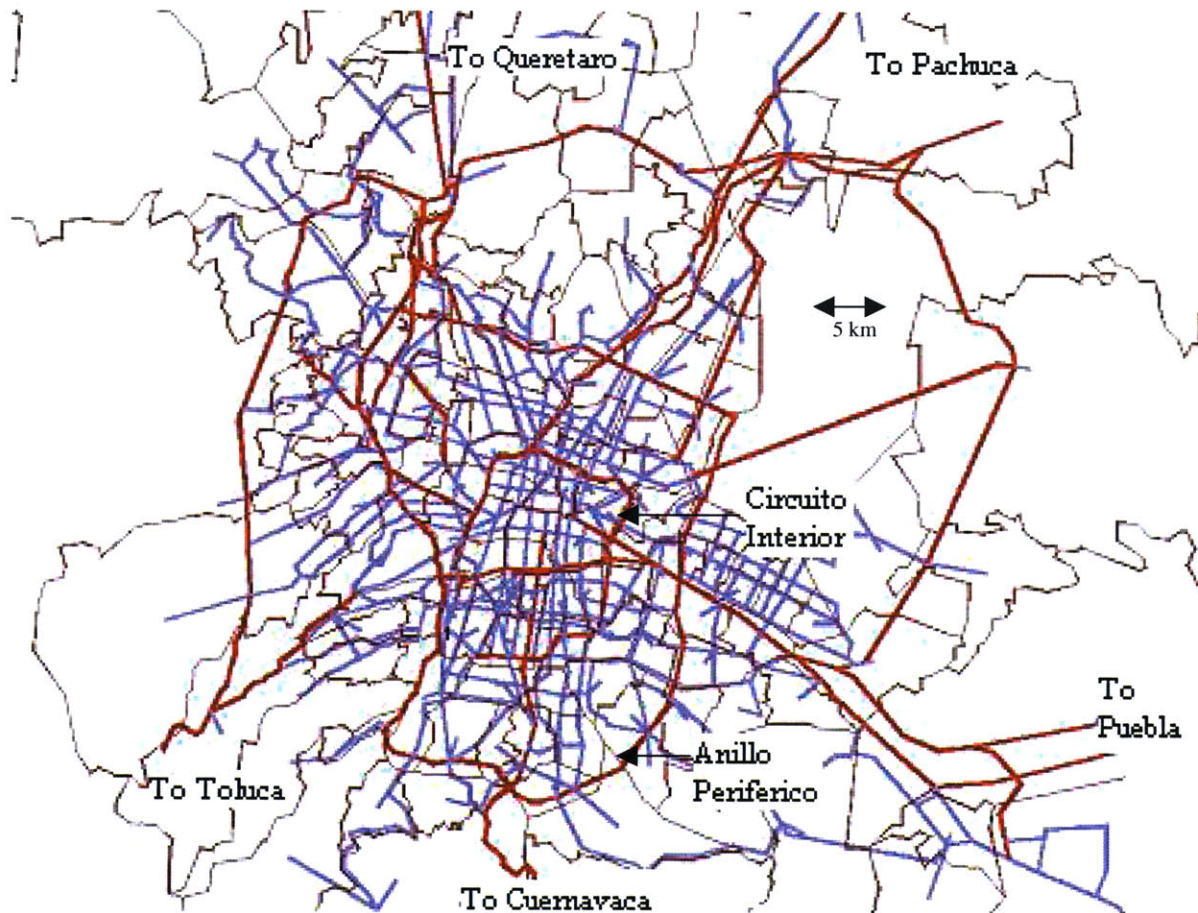


Figure 4.1- Transcad Roadway Network of the Mexico City Metropolitan Area

Because the MCMA is surrounded by mountains, the transportation network is a somewhat closed system, with a few highways leading out of the city to the rest of Mexico.

## 4.1 Speed Distribution

One of the most important results of the Transcad modeling is the speed distribution of all vehicle trips. In order to calculate the emissions from vehicles, a vehicle speed is required to reflect the driving cycle. If a vehicle were traveling at a slow speed, it is likely to be in stop and go traffic, and would create a greater amount of emissions. However, in previous emissions inventories for vehicles in the MCMA, a set average speed of 32 kph was assumed. This speed essentially averages all slow and fast moving vehicles; this will likely underestimate emissions, because vehicles pollute more at extremely slow or fast speeds. Transcad allows us to determine the number of vehicle-kilometers traveled across the entire speed range, as shown in Figure 4.2.

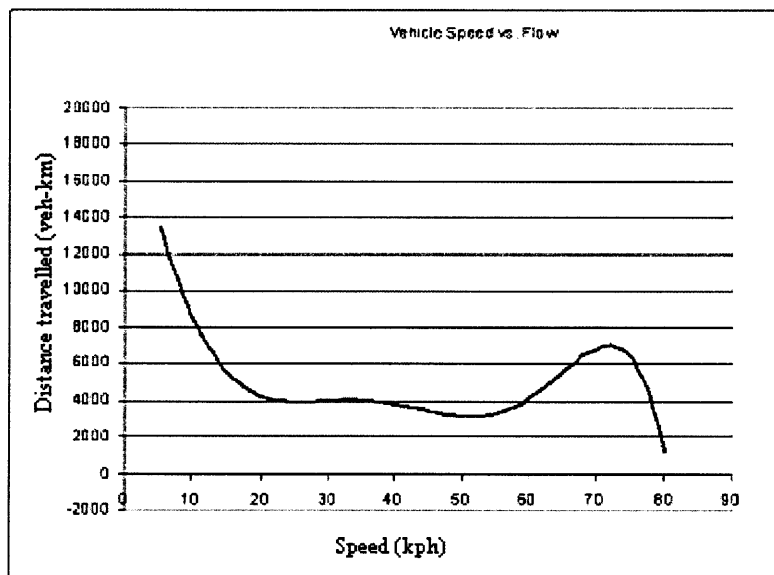


Figure 4.2- Number of Vehicles Traveling at 5 to 80 kph each hour, 1994 OD data

Figure 4.3 shows the speed distribution for both the 1994 and 2025 OD data. The number of trips taken in 2025 is significantly higher than in 1994. This results in not only an increase in vehicle flow, but also a shift towards slower vehicle speeds. While many vehicles in 1994 traveled at speeds between 20 and 50 kph, vehicles in 2025 are projected to travel at much slower speeds, between 0 and 30 kph. This increase in congestion has a significant upward impact on emissions estimates.



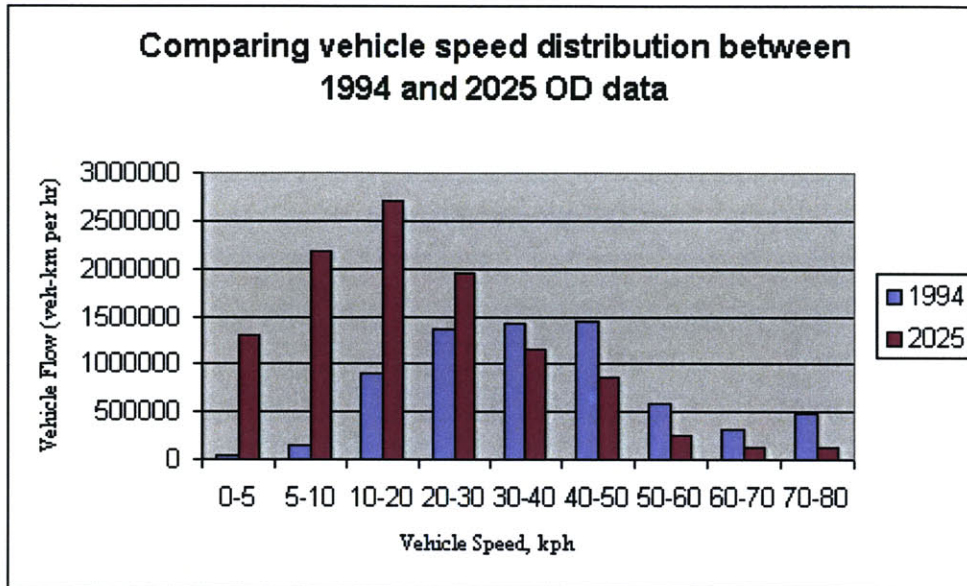


Figure 4.3- 1994 and 2025 speed distribution

#### 4.2 Emissions estimates

Using this speed distribution, it is possible to use an emissions model such as MOBILE6 to determine the effect of congestion on emissions estimates. The following table summarizes the comparison between the old “one speed” method and the network model method for the 1994 OD data.

1994 OD Data	HC emissions (Tonnes/hr)	CO emissions (Tonnes/hr)	Nox emissions (Tonnes/hr)
Old method (32 kph)	28.67	290.8	23.76
Network model method	26.62	269.9	25.12

Table 4.1- Emissions Data for 1994

The results obtained are surprising- emissions using the network model for hydrocarbons and carbon monoxide are actually underestimated compared to the old method, while emissions for nitric oxides are overestimated. Because a large number of vehicles are still traveling at higher uncongested speeds where emissions are lowest, the

congested vehicle emissions are offset by these lower emissions vehicles. This is illustrated in Figure 4.4.

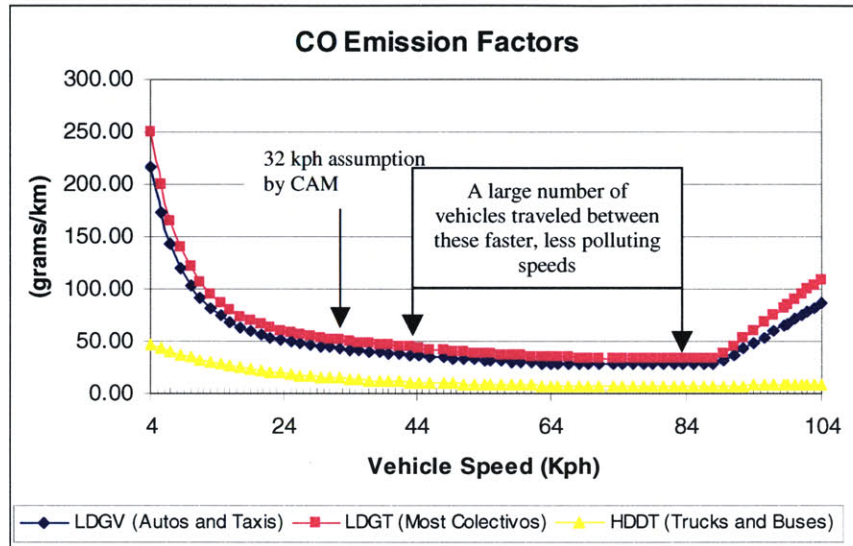


Figure 4.4- Vehicle speed vs. emissions for CO, 1994 data

However, if we were to run the network model again using projected population and economic growth for a year 2025 scenario, the results show that the old model significantly underestimates emissions.

2025 OD data	HC emissions (Tonnes/hr)	CO emissions (Tonnes/hr)	Nox emissions (Tonnes/hr)
Old method (32 kph)	47.31	480.2	39.60
Network model method	82.59	877.3	45.36

Table 4.2- Emissions Data for 2025

The level of congestion on roadways in the 2025 scenario have become a significant factor in an increase in emissions.



### 4.3 Spatial representation

The other important aspect of the Transcad model is the spatial representation of traffic in the city. Because we are modeling individual roadway segments, it is possible to determine which areas of the city face the highest levels of congestion. These results can be compared with spatial atmospheric pollutant models in order to determine a correlation between auto emissions and congestion.

One method for showing the level of congestion on each roadway link is to use the volume/capacity ratios as an index. Vehicle flow on each segment would not be a good indicator, because some roadways such as highways can carry a higher capacity than arterials. By using the volume/capacity ratio on each roadway link, we can see the relative level of congestion throughout the city.

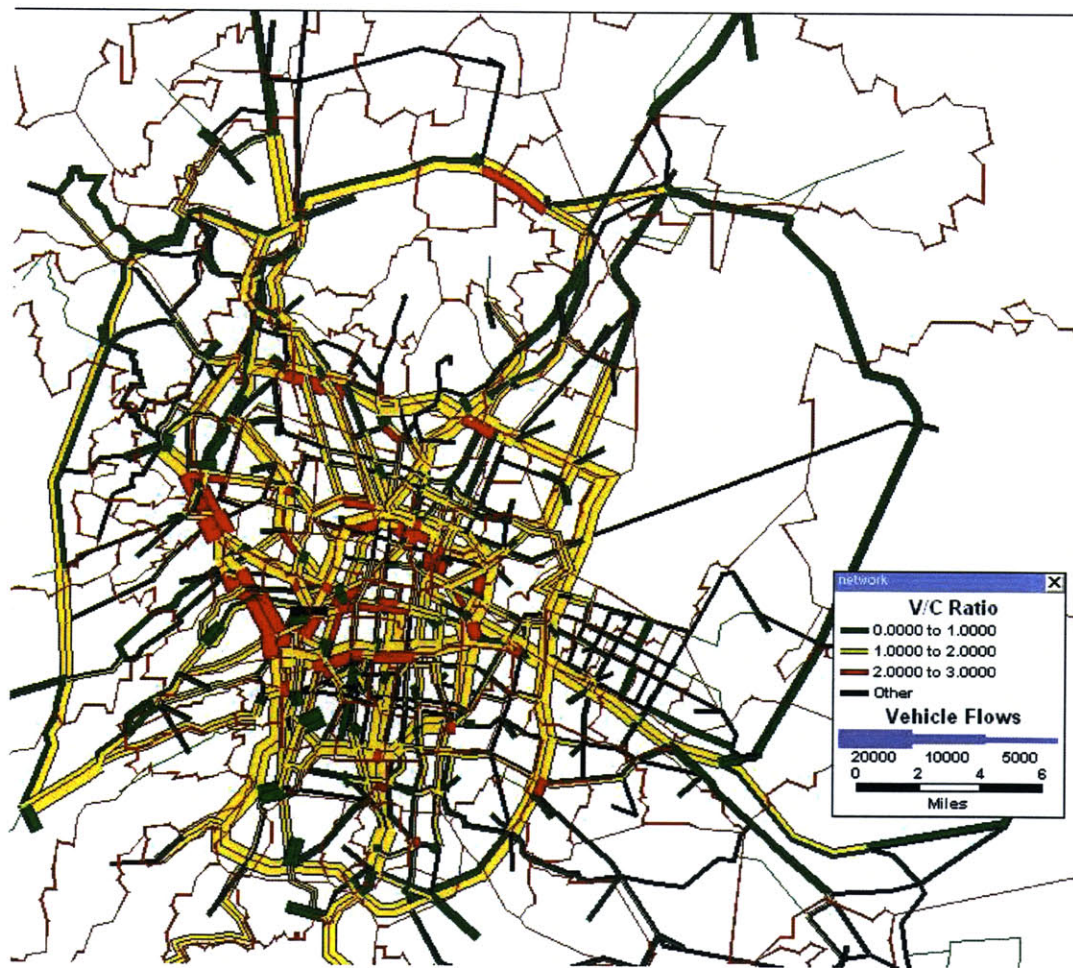


Figure 4.5- Spatial representation of congestion for 1994 data

Figure 4.5 shows the spatial representation of congestion in the MCMA using the 1994 OD data. The *Periferico* loop highway and the *Circuito Interior* inner loop highway are both at moderate congestion levels, while many of the secondary roadways are uncongested. One particularly problematic area is the western area of the city. The area along the western side of the *Periferico* loop lies along the wealthier section of Mexico City. As a result, we can see the effects of the higher vehicle ownership and usage rate on this area. The roadways leading out of Mexico City to Toluca to the west and Cuernavaca to the south are also moderately congested.

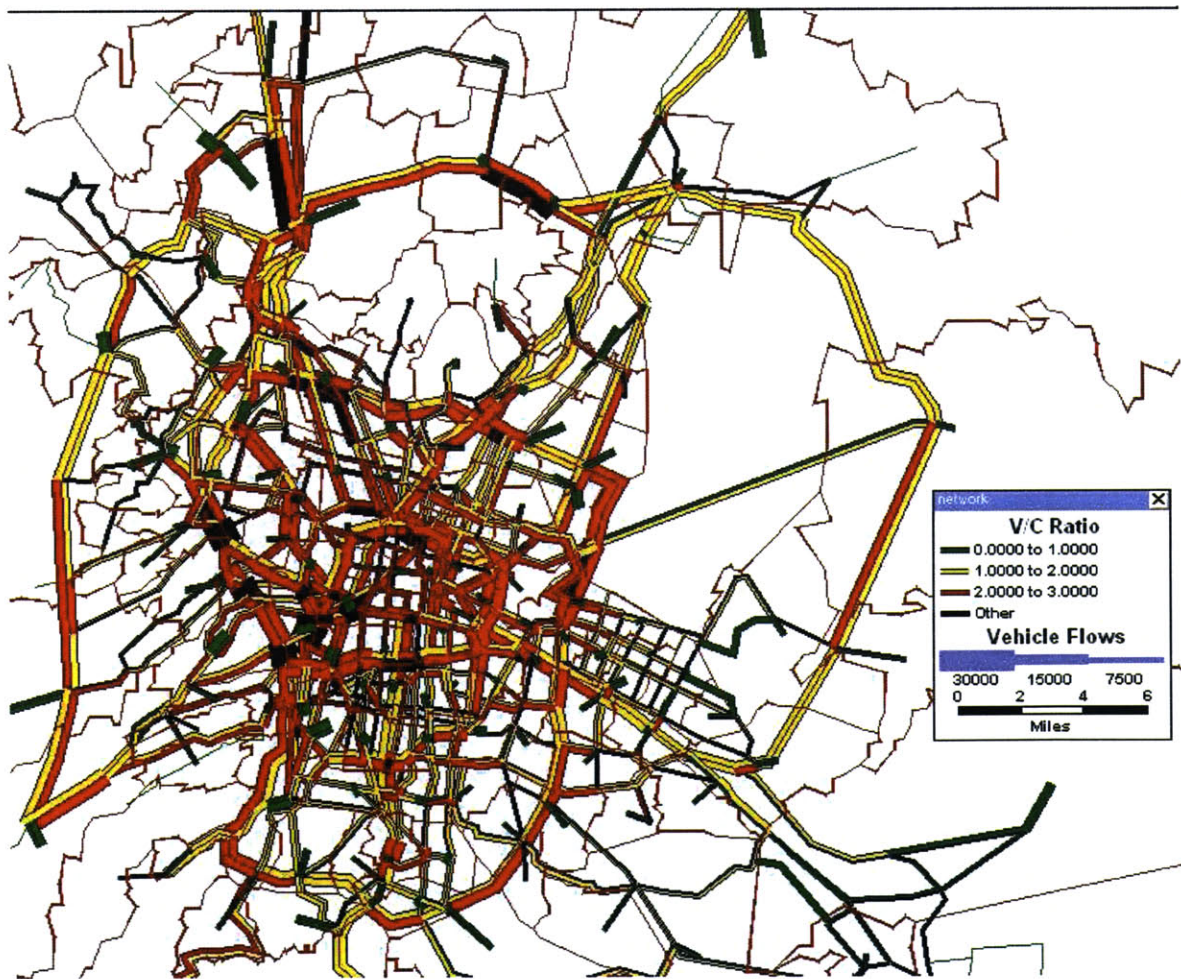


Figure 4.6- Spatial representation of congestion for 2025 data

For the 2025 OD data, we can see that the level of congestion on most roadways has significantly increased. Most of the roadways in the city center are now moderately congested, and the western section of the *Periferico* loop is now severely congested. Congestion has also spread outward from the city center in the Federal District, due to population growth and sprawl in that area. We can no longer pinpoint one bottleneck in this map as reflected in the areas highlighted in black- the network has become saturated to the point that all roadways are affected.

#### 4.4 Infrastructure improvement analysis

As part of the congestion modeling process, we modeled various future infrastructure improvements. These included the effects of constructing the *Segundo Piso*, or a second tier to the *Periferico* loop highway, and plans for the addition of a new Metro line.

##### 4.4.1 *Segundo Piso* addition

Plans have been drawn up to construct a second level above the existing *Periferico* loop highway. In an effort to estimate the effect this infrastructure change has on congestion, we doubled the vehicle capacity for the *Periferico* and reran the model. The following change in the vehicle speed distribution was observed:



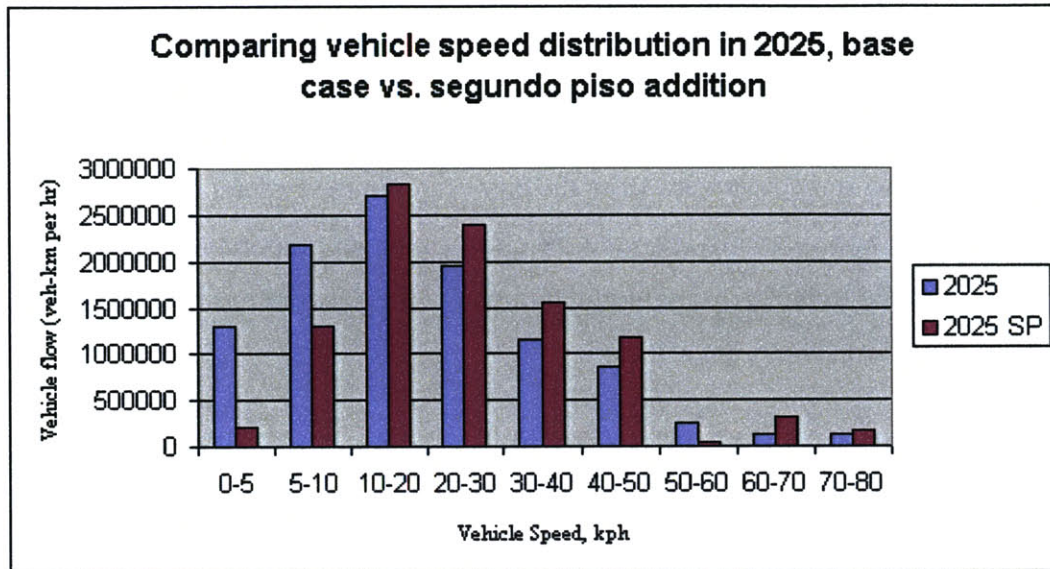


Figure 4.7- Impact of Segundo Piso addition on 2025 vehicle speed distribution

The addition of the second deck significantly decreased the number of vehicles traveling at the slowest speeds. This has an impact on the emissions estimates as well.

2025 OD Data	HC emissions (Tonnes/hr)	CO emissions (Tonnes/hr)	Nox emissions (Tonnes/hr)
Base case	82.59	877.3	45.36
With Segundo Piso	62.39	649.3	42.39

Table 4.3- Emissions Data for 2025 With Segundo Piso

Emissions in HC and CO are reduced by 25 percent with the construction of the *Segundo Piso*. In addition, mobility in the city increases, as shown in Figure 4.8.

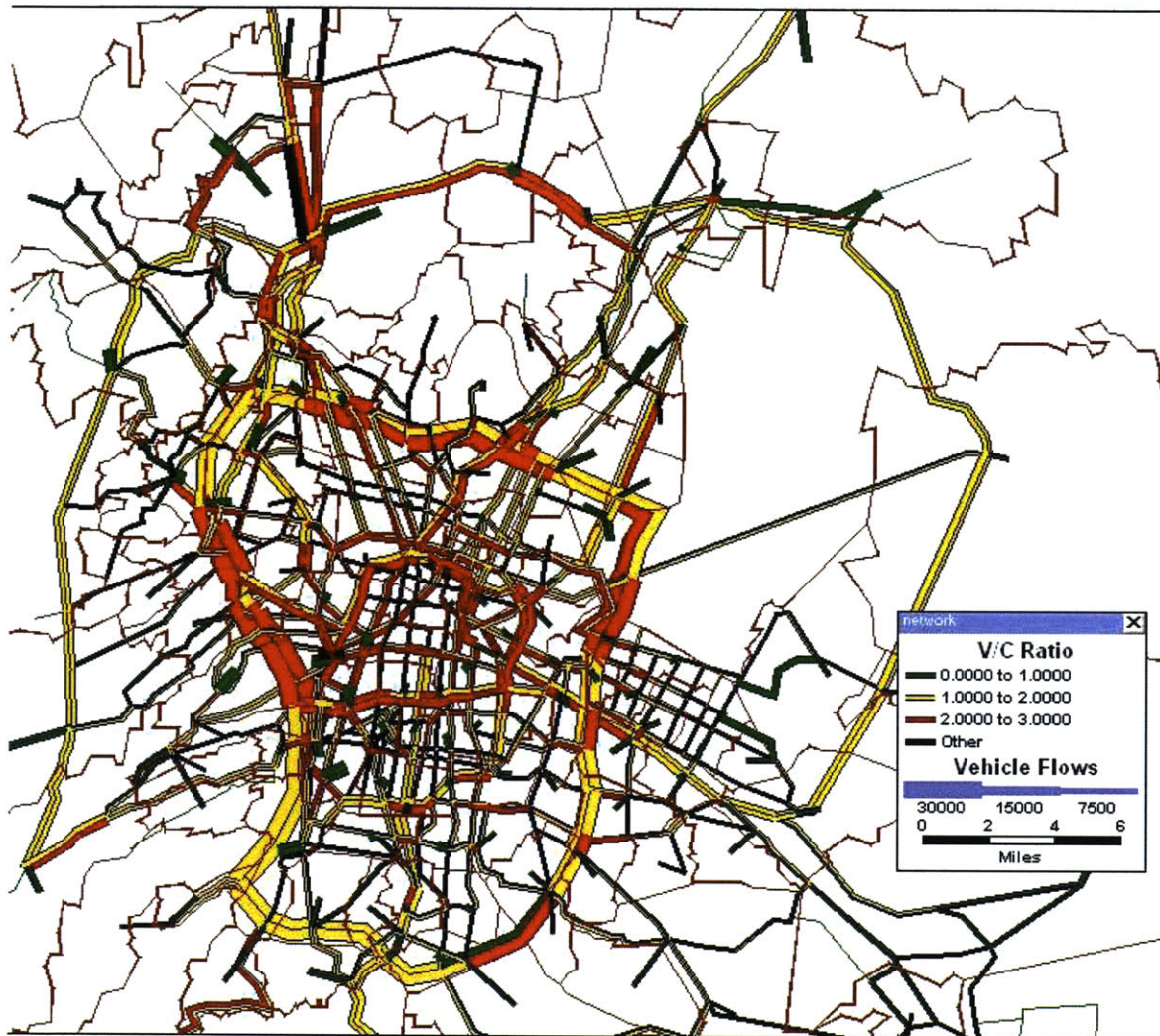


Figure 4.8- Spatial representation of 2025 data with Segundo Piso addition

Congestion has decreased to moderate levels along the *Periferico* and *Circuito Interior*. However, the level of congestion on the surrounding roadways has also decreased. We can therefore assume that an infrastructure improvement on one roadway can have a significant impact on the surrounding roadways. One important caveat to this scenario analysis is that no induced demand is added due to the construction of the *Segundo Piso*. With a new highway, it is expected that more people will drive due to a faster, more convenient commute.

#### 4.4.2 Metro expansion

In addition to roadway infrastructure improvements, there are plans to expand the Mexico City metro network as well. According to the most recent government air quality plan for Mexico City (PROAIRE), the metro will double its track length by the year 2020, with service expanding radially from the city core to the outlying suburbs. In addition, while all but one of the current metro lines service only the Federal District, the expansion calls for new lines into the State of Mexico.

One of these lines, line C, runs northwestward from the city center to the city of Cuautitlan Izcalli in the State of Mexico. This line would run parallel with one of the most congested roadways in the city- the Autopista Queretaro. In order to incorporate the possible impact this new line would have on roadway congestion, the mode split for distritos along this route was shifted from road-based transportation sources such as private auto and colectivo to metro service.



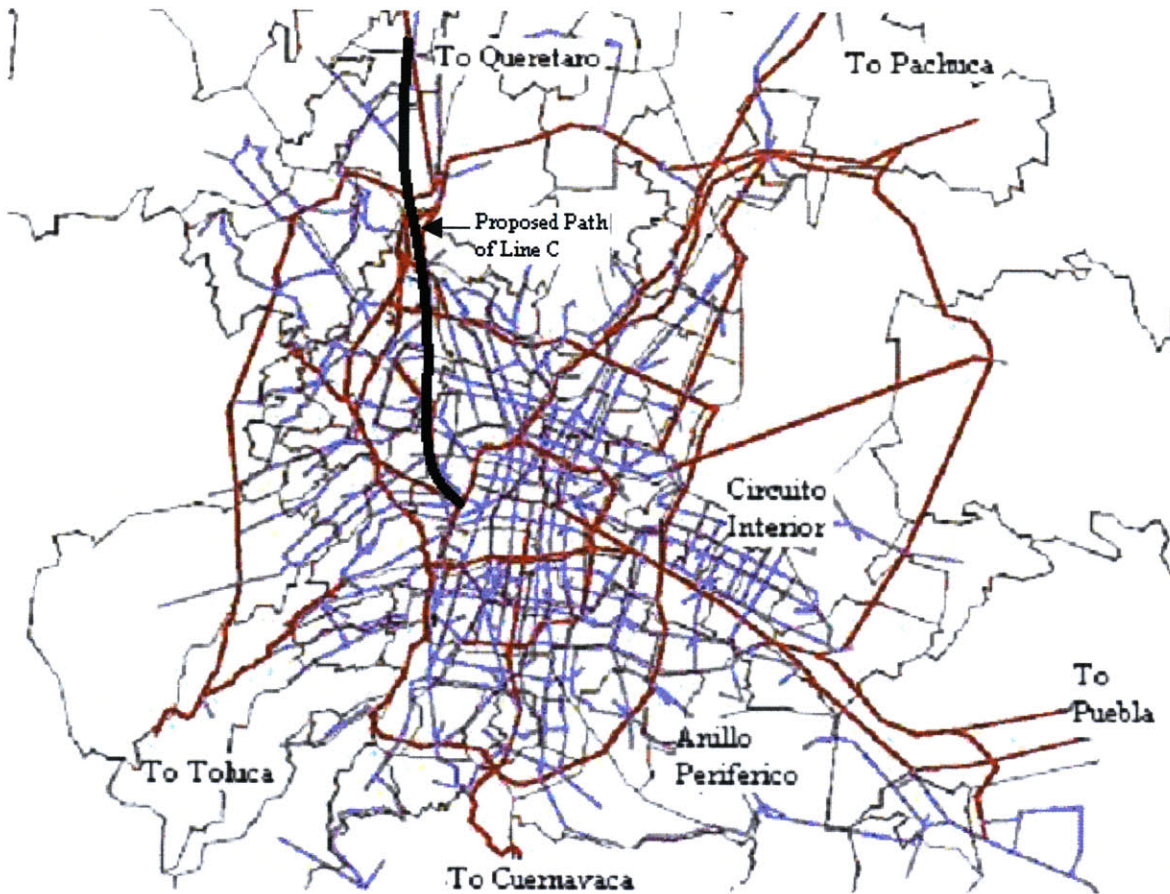


Figure 4.9- Path for Line C Metro Expansion

It was unknown how this new metro line would quantitatively affect the mode split, so we ran the model under 3 tests for a sensitivity analysis. The mode share for all road based transportation trips in distritos along the new line was shifted to metro service by 5%, 10%, and 15%. The affected distritos are listed in Appendix B. Using these updated 2025 OD trip matrices, we reran the model.

The results showed that there was only a slight reduction in congestion along the major roadways parallel to the new metro line.

Roadway parallel to new metro line	2025 V/C	2025 V/C, 5% shift	2025 V/C, 10% shift	2025 V/C, 15% shift
Aguiles Serdan	2.23	2.23	2.21	2.18
Via Gustavo Baz Prada	1.90	1.89	1.85	1.82
Autopista Mexico-Queretaro	2.76	2.76	2.75	2.73

Table 4.4- V/C Ratios on Roadways Parallel to New Metro Line

This reduction has no significant impact on congestion; roadway conditions will not improve significantly according to this model, if only 15% of the traffic shifts to the Metro.

However, it is difficult to take into account all trip and mode split effects of a new metro line. This model only changed the mode split for trips between distritos along the new line, but people may transfer to other lines/modes and continue their trips throughout the rest of the MCMA. As a result, our current network model is not sufficient to accurately estimate the effect of a new metro service.



## Chapter 5- Conclusions

### 5.1 Summary of results

Overall, the model described in this thesis is a good tool for spatially recognizing areas of congestion and predicting vehicle speeds and emissions. On a citywide scale, we can determine areas that face severe congestion and recommend more public transportation access in those areas. On a more local scale, we can identify bottleneck areas and gain a better understanding of conditions along major corridors. However, the model is not a good tool for determining the conditions on a microscopic scale. Due to the lack of all roadway segments and the large size of the OD zones, link specific results may give inaccurate estimates of vehicle flow and speed.

While the inputs and outputs of the model are on a link by link basis, the most important results are on a macroscopic scale, such as the citywide vehicle speed distribution. With further refining of the model, it may be possible to pinpoint specific roadways that face heavy congestion.

In addition, because this model can give us an indication of the state of transportation in the future, the government can anticipate trouble spots and take steps today in order to maintain an adequate level of mobility and limit emissions. The scenarios analysis showed that new roadway capacity construction can be modeled easily. However, shifts in mode share due to new bus, metro, or colectivo lines are more difficult to model, due to the complexity of the interactions between the new line and existing lines.

### 5.2 Improvements to the network model

This model can be improved in a variety of ways. The inclusion of one-way streets will more accurately reflect the state of travel in the city. Many of the *ejes viales*, or the roadways in the grid network of the city center, are wide avenues with traffic

flowing in one direction. These one way roads may have a significant impact on the network results.

The model currently consists of only the major roadways in the city. While it is believed that most travel occurs along these major roadways, secondary roadways are also used as feeder routes or for short-distance trips. This may reduce the travel time on short length trips between adjacent distritos. Figure 5.1 compares the current roadway network with a complete roadway network.

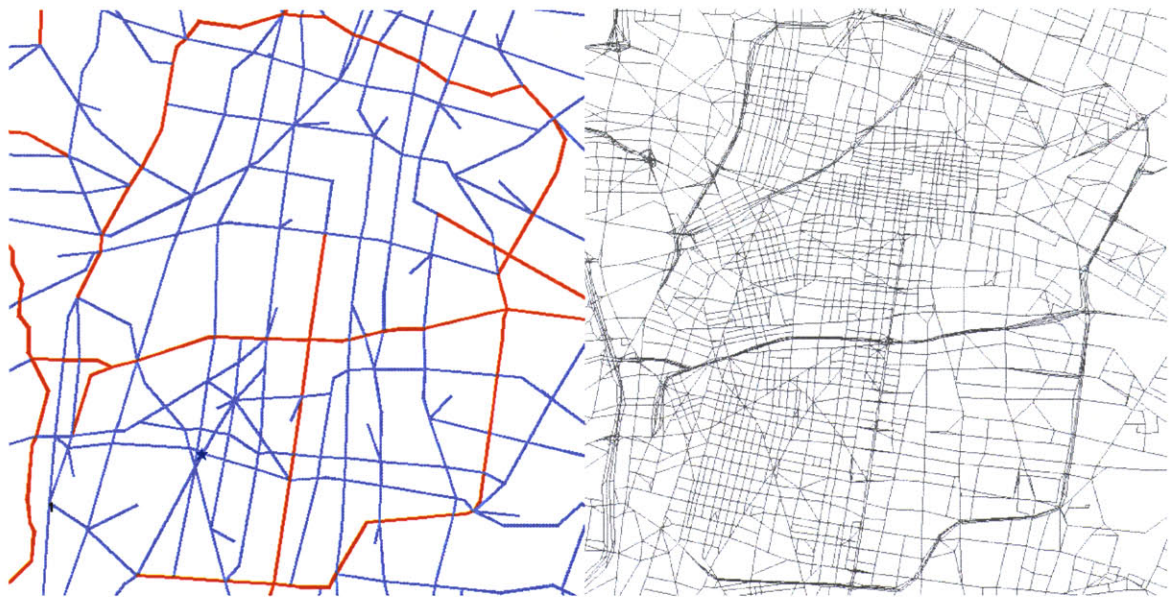


Figure 5.1- Comparison between skeletal and full roadway networks

The freight component of the network model can also be improved. For simplicity, we assumed that freight composed 10 percent of all trips in the OD matrix. In reality, there would be a greater number of freight trips near cargo terminals or the highways leading out of the MCMA, and these trips would take place at various hours of the day. Using improved freight data, it may be possible to model the freight component of the network model more precisely.

### 5.3 Limitations of the network model

One major limitation in the network model is the absence of induced demand. In the case of the *Segundo Piso* scenarios analysis, the model showed that congestion would be reduced with the construction of this infrastructure improvement. However, new roadways and public transportation lines generate new transportation routes. The convenience of a new highway or metro station may spur businesses and residences to move nearby, creating additional traffic. In addition, while a new highway may increase vehicle capacity, the surface roadways feeding into and out of the highway may not be able to handle the increased demand.

This network model also does not take into account the spread of congestion from one roadway segment to adjacent segments. This is illustrated in Figure 5.2.

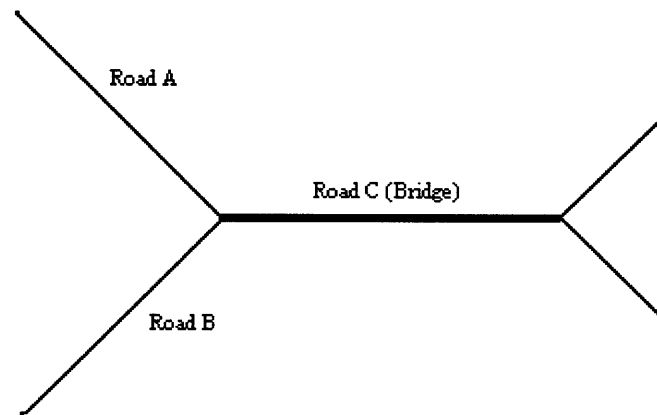


Figure 5.2- Bottleneck congestion scenario

For example, traffic on roads A and B merge to cross a bridge at road C. Because of the bottleneck at the bridge, there is significant congestion on road C. However, Transcad models these roadways as separate segments, so congestion on road C does not physically back up into roads A and B. Bottlenecks such as these in the MCMA network do not spread to adjacent roadways. As a result, vehicle speeds may be overestimated along these adjacent roadways.

This model also lacks a feedback loop between mode choice and roadway conditions. A commuter that is faced with traffic jams every day may switch from auto to the metro, may adjust their departure time, or change routes. However, because the mode choice matrix was taken from an OD survey and not a LOGIT or similar mode choice model, this network model cannot adjust for these changes.

#### 5.4 Future work

Now that we have developed a network model of Mexico City, we can learn from its limitations and results to improve it. Using the results of the network model, we can create new improvements that may improve the state of congestion in Mexico City. Focusing on the congested areas, we can attempt to model the impacts of new infrastructure systems, such as a bus rapid transit line on a congested corridor, or a new freight terminal outside the city. Hybrid vehicles may also be a useful way for reducing emissions in a congested city. Because hybrid vehicles use non-polluting electric power at low vehicle speeds, emissions from stop-and-go traffic conditions are reduced significantly. Using the vehicle speed distributions obtained from the network model, it may be possible to estimate the effects of hybrid vehicles.

Another option is to rebuild the network model with an improved framework. Other modeling software can incorporate the effects of the feedback loop between mode choice and roadway conditions. One such software package is the *Estraus* model developed for the city of Santiago, Chile. By integrating the traffic assignment model with a LOGIT mode choice model and solving both jointly, *Estraus* can more accurately represent the state of transportation in a city. A mode choice matrix is no longer necessary- the *Estraus* model is capable of assigning a mode, depending on the utility of each trip, such as proximity to a metro stop, travel time, or auto ownership.

Overall, the development of this network model has given us some useful insight into the state of transportation in Mexico City, and the limitations of our network model and methods to improve it. While the initial goal was to more accurately estimate

congestion and emissions in the city, the development of this model has been a first step towards opening the door to modeling with a more precise and complete network.

## Appendix A- Emissions factors based on vehicle speed

Source- COMETRAVI report based on MOBILE5 emissions model

Km/hr	LDGV (Autos and Taxis)			LDGT (Most Colectivos)			HDDT (Trucks and Buses)		
	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
4	18.62	216.35	2.01	22.46	249.52	2.34	13.60	46.80	31.08
5	18.62	216.35	2.01	22.46	249.52	2.34	13.60	46.80	31.08
6	14.40	173.45	1.89	17.46	200.30	2.19	12.95	43.33	29.83
7	11.79	142.94	1.78	14.36	165.39	2.07	12.34	40.18	28.68
8	11.79	142.94	1.78	14.36	165.39	2.07	12.34	40.18	28.68
9	10.00	120.69	1.70	12.21	139.92	1.96	11.77	37.32	27.60
10	8.69	104.11	1.63	10.62	120.93	1.88	11.24	34.72	26.60
11	7.71	91.55	1.58	9.43	106.50	1.82	10.73	32.35	25.66
12	7.71	91.55	1.58	9.43	106.50	1.82	10.73	32.35	25.66
13	6.99	81.86	1.54	8.56	95.35	1.76	10.26	30.19	24.78
14	6.42	74.30	1.51	7.86	86.62	1.72	9.81	28.22	23.97
15	6.42	74.30	1.51	7.86	86.62	1.72	9.81	28.22	23.97
16	5.95	68.31	1.49	7.29	79.71	1.70	9.40	26.41	23.21
17	5.56	63.51	1.48	6.82	74.16	1.69	9.00	24.77	22.50
18	5.56	63.51	1.48	6.82	74.16	1.69	9.00	24.77	22.50
19	5.24	59.64	1.48	6.42	69.67	1.69	8.63	23.26	21.84
20	4.97	56.46	1.49	6.09	65.99	1.69	8.28	21.88	21.23
21	4.97	56.46	1.49	6.09	65.99	1.69	8.28	21.88	21.23
22	4.74	53.84	1.50	5.81	62.94	1.71	7.96	20.62	20.66
23	4.54	51.64	1.53	5.56	60.39	1.73	7.65	19.45	20.13
24	4.54	51.64	1.53	5.56	60.39	1.73	7.65	19.45	20.13
25	4.37	49.78	1.55	5.35	58.24	1.76	7.36	18.38	19.63
26	4.21	48.18	1.59	5.16	56.39	1.79	7.08	17.40	19.18
27	4.21	48.18	1.59	5.16	56.39	1.79	7.08	17.40	19.18
28	4.08	46.78	1.62	4.99	54.77	1.83	6.82	16.50	18.75
29	3.96	45.54	1.66	4.84	53.34	1.86	6.58	15.67	18.36
30	3.96	45.54	1.66	4.84	53.34	1.86	6.58	15.67	18.36
31	3.85	44.41	1.70	4.70	52.05	1.91	6.34	14.90	18.00
32	3.75	43.37	1.74	4.59	50.93	1.96	6.13	14.19	17.67
33	3.75	43.37	1.74	4.59	50.93	1.96	6.13	14.19	17.67
34	3.66	42.40	1.79	4.49	49.86	2.01	5.92	13.54	17.36
35	3.58	41.48	1.84	4.39	48.85	2.07	5.72	12.94	17.09
36	3.58	41.48	1.84	4.39	48.85	2.07	5.72	12.94	17.09
37	3.50	40.60	1.89	4.30	47.88	2.12	5.54	12.39	16.83
38	3.43	39.74	1.93	4.22	46.94	2.17	5.37	11.88	16.60
39	3.43	39.74	1.93	4.22	46.94	2.17	5.37	11.88	16.60
40	3.36	38.90	1.98	4.14	46.02	2.23	5.20	11.40	16.40
41	3.30	38.07	2.03	4.07	45.12	2.28	5.05	10.96	16.22
42	3.30	38.07	2.03	4.07	45.12	2.28	5.05	10.96	16.22
43	3.24	37.26	2.07	4.00	44.23	2.34	4.90	10.56	16.05
44	3.18	36.47	2.12	3.93	43.35	2.39	4.76	10.19	15.91
45	3.18	36.47	2.12	3.93	43.35	2.39	4.76	10.19	15.91
46	3.12	35.68	2.16	3.86	42.49	2.44	4.63	9.84	15.79
47	3.12	35.68	2.16	3.86	42.49	2.44	4.63	9.84	15.79

48	3.05	34.68	2.22	3.78	41.37	2.50	4.46	9.43	15.66
49	3.00	34.00	2.26	3.72	40.62	2.55	4.35	9.18	15.62
50	3.00	34.00	2.26	3.72	40.62	2.55	4.35	9.18	15.62
51	2.95	33.32	2.29	3.67	39.86	2.58	4.25	8.94	15.59
52	2.91	32.64	2.33	3.61	39.10	2.63	4.14	8.69	15.55
53	2.91	32.64	2.33	3.61	39.10	2.63	4.14	8.69	15.55
54	2.86	31.96	2.37	3.56	38.34	2.67	4.04	8.44	15.52
55	2.83	31.51	2.39	3.52	37.84	2.69	3.97	8.28	15.49
56	2.79	30.93	2.42	3.47	37.19	2.73	3.86	8.05	15.52
57	2.79	30.93	2.42	3.47	37.19	2.73	3.86	8.05	15.52
58	2.75	30.39	2.45	3.43	36.59	2.76	3.79	7.92	15.54
59	2.72	29.90	2.48	3.39	36.03	2.80	3.71	7.76	15.60
60	2.72	29.90	2.48	3.39	36.03	2.80	3.71	7.76	15.60
61	2.68	29.47	2.50	3.35	35.54	2.82	3.64	7.62	15.68
62	2.65	29.07	2.52	3.31	35.10	2.85	3.57	7.49	15.77
63	2.65	29.07	2.52	3.31	35.10	2.85	3.57	7.49	15.77
64	2.62	28.74	2.54	3.28	34.72	2.87	3.50	7.38	15.88
65	2.61	28.54	2.56	3.26	34.49	2.89	3.46	7.31	15.97
66	2.58	28.28	2.58	3.23	34.21	2.91	3.39	7.22	16.13
67	2.58	28.28	2.58	3.23	34.21	2.91	3.39	7.22	16.13
68	2.56	28.08	2.59	3.21	33.97	2.93	3.34	7.14	16.30
69	2.54	27.93	2.61	3.19	33.80	2.95	3.28	7.07	16.49
70	2.54	27.93	2.61	3.19	33.80	2.95	3.28	7.07	16.49
71	2.53	27.92	2.63	3.17	33.68	2.97	3.23	7.01	16.71
72	2.53	27.92	2.63	3.17	33.68	2.97	3.23	7.01	16.71
73	2.51	27.74	2.66	3.16	33.59	3.00	3.18	6.96	17.04
74	2.50	27.72	2.68	3.14	33.57	3.02	3.13	6.93	17.31
75	2.50	27.72	2.68	3.14	33.57	3.02	3.13	6.93	17.31
76	2.49	27.73	2.69	3.13	33.58	3.04	3.09	6.91	17.61
77	2.48	27.74	2.72	3.13	33.61	3.07	3.05	6.90	17.94
78	2.48	27.74	2.72	3.13	33.61	3.07	3.05	6.90	17.94
79	2.48	27.74	2.76	3.12	33.61	3.12	3.02	6.90	18.29
80	2.48	27.74	2.80	3.12	33.61	3.18	2.99	6.92	18.68
81	2.48	27.74	2.80	3.12	33.61	3.18	2.99	6.92	18.68
82	2.48	27.74	2.85	3.12	33.61	3.23	2.96	6.94	19.09
83	2.48	27.74	2.85	3.12	33.61	3.23	2.96	6.94	19.09
84	2.47	27.74	2.89	3.12	33.61	3.29	2.93	6.98	19.54
85	2.47	27.74	2.94	3.11	33.61	3.34	2.90	7.03	20.03

Appendix B-

Distritos that fell along the new metro line:

Zona Rosa

Condesa

Chapultepec

Panteones

Anahuac

La Raza

Claveria

Tezozomoc

El Rosario

Vallejo

Santa Monica

Puente De Vigas

Centro Industrial

Sta. Cecilia

Jardines Del Recuerdo

Maza De Juarez

Lecheria, La Piedad

Infonavit Izcalli

Cd. Labor



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